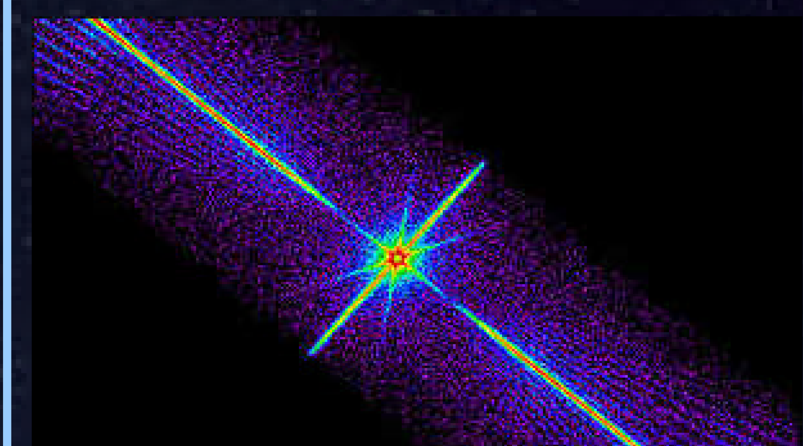
Flux Transformers for Magnetic Microcalorimeter X-Ray Detector Arrays

Brett Bethke*, Dr. Simon Bandler**, Dr. Thomas Stevenson***
*2003 NASA Academy Research Associate. MIT, Cambridge, MA
**Co-Investigator. Code 662, NASA Goddard Space Flight Center, Greenbelt, MD
***Principal Investigator. Code 553, NASA Goddard Space Flight Center, Greenbelt, MD

Introduction


X-ray image of a black hole, taken by Chandra

Some of the most interesting objects in the Universe - black holes, neutron stars, white dwarfs, supernovae, active galactic nuclei, etc. - emit X-ray radiation. By studying this radiation, we can learn about the fundamental physics that governs matter and energy in extreme, high-energy environments not found on the Earth. In order to study X-rays, highly sensitive X-ray detectors are required. Currently, efforts are underway to develop the next generation of detectors for X-ray astronomy.

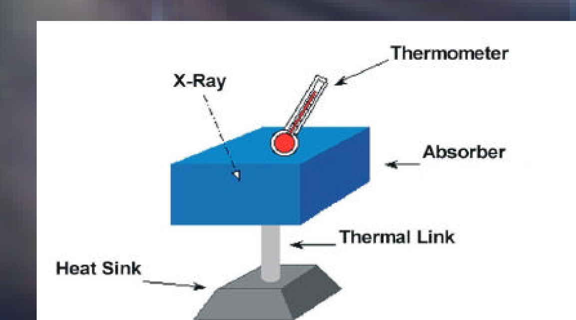
The Chandra X-Ray Observatory


The Chandra X-Ray Observatory

Launched by Space Shuttle Columbia in 1999, the ndra X-Ray Observatory is currently the most nisticated X-ray telescope in operation. While images returned by Chandra have changed our erstanding of the universe, the observatory's itivity and energy resolution are not high enough to allow scientists to study the finest details of cosmic X-ray sources. One-third of the sources viewed by Chandra are too faint for X-ray spectroscopy and their nature remains a mystery.

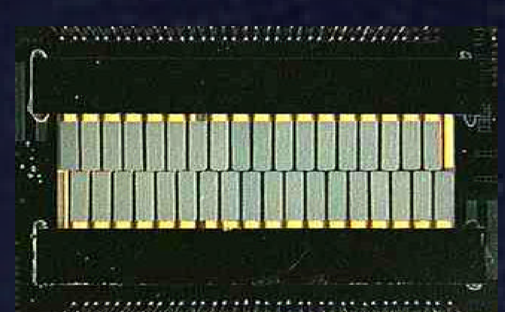
Microcalorimeter X-Ray Detectors

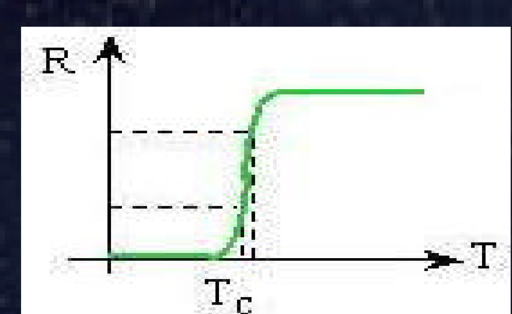
Microcalorimeters - small devices for measuring energy absorbed in the form of heat - can be used to detect X-rays. A microcalorimeter consists of an absorber that is weakly thermally coupled to a constant-temperature heat sink. The microcalorimeter has a thermometer which can measure changes in the device's temperature. When an X-ray photon is absorbed, the energy of the photon is converted into heat. By measuring the resulting temperature change, the energy of the photon can be determined. The microcalorimeter quickly returns to the equilibrium temperature of the heat sink, readying it to detect another photon.



Microcalorimeter diagram

Temperature response to photon absorption


XRS 2X18 semiconducting thermistor detector array

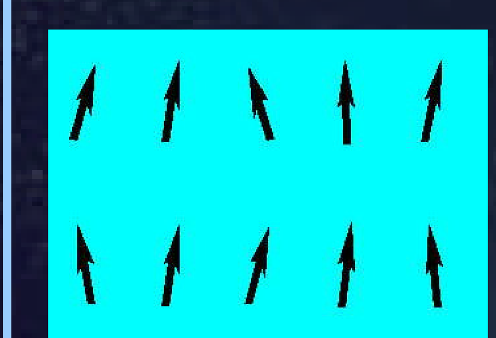


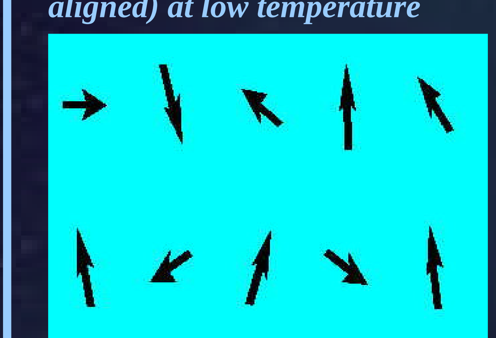
Resistance vs. temperature curve for a superconductor

Although conceptually simple, there are many ways of designing a microcalorimeter. Designs include:

*** Semiconducting thermistors**
*** Transition Edge Sensors**
*** Magnetic microcalorimeters (discussed below)**

Magnetic Microcalorimeters


Large magnetization (spins aligned) at low temperature


Small magnetization (spins random) at high temperature

The thermometer in a magnetic microcalorimeter consists of a sensor made of a metallic host material containing a dilute concentration of paramagnetic ions. In an applied magnetic field, the magnetization of the sensor approximately obeys a 1/T Curie law. A temperature change resulting from an X-ray photon absorption therefore causes a change in the magnetization of the sensor. This change can be detected by placing the sensor directly over a Superconducting Quantum Interference Device (SQUID), or by using an intermediate *flux transformer*. In the transformer scheme, a superconducting pickup coil is placed around the sensor. The pickup coil is connected to the input coil of a SQUID. The changing magnetic flux produces a current signal in the coils, which is detected and amplified by the SQUID. By monitoring the signal from the SQUID, the timing and energies of the incoming X-ray photons can be determined.

Our project aims to develop arrays of magnetic calorimeters. Using flux transformers with lithographic (on-chip) pickup coils allows the magnetic sensors and the SQUIDs to be made on separate chips and simplifies the overall fabrication process of large detector arrays.

Personal Contribution

- **Build superconducting field coil to apply a steady magnetic field to the sensors**
- **Modify sensor mounting hardware to accept field coil**
- **(Expected) Install sensors into cryostat**
- **(Expected) Measure Johnson noise spectrum of the sensors**
- **(Expected) Use noise spectrum data to calculate the inductance of the flux transformer coils, derive magnetic coupling efficiency, and compare to model.**

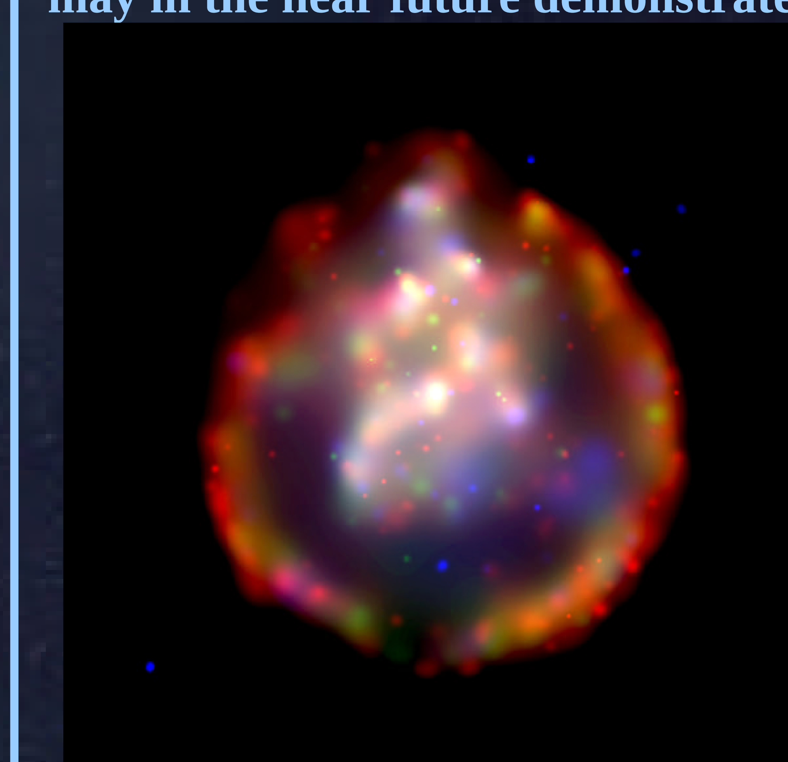
Constellation-X

A key element of NASA's "Structure and Evolution of the Universe" program, Constellation-X is a proposed X-ray telescope mission that could be launched as early as 2011. Consisting of four identical orbiting spacecraft, Constellation-X will provide a 25- to 100-fold increase in sensitivity over Chandra. While Chandra's energy resolution is roughly 100eV, the detectors aboard Constellation-X will have resolutions near 2eV. This will enable it to analyze extremely faint X-ray sources for chemical composition as well as test our understanding of physics in the extreme environments near black holes.


Constellation-X

Conclusion

Magnetic microcalorimeters are promising X-ray detectors that may in the near future demonstrate the ~2eV energy resolution required for sensitive X-ray missions such as Constellation-X. A large array of such detectors, coupled with precision optics, will allow for unprecedented observations of energetic X-ray sources. Data from these observations will test the limits of our physical theories and deepen our understanding of the Universe.


X-ray image of supernova remnant SNR 0103-72.6

Acknowledgements

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